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EFFECT OF THE PORE SPACE ON THE STRENGTH OF CERAMICS

G. D. Ashmarin,[1,5] A. M. Salakhov,[1] N. V. Boltakova,[2] V. P. Morozov,[3] V. N. Gerashchenko,[4] and R. A. Salakhova[4]

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The results of studies of the effect of the pore space and microcracks on ceramic strength are presented.

Key words: ceramic materials, structure, pores, microcracks, strength, computer tomography.

A large group of specialists believes, justifiably so, that clay minerals, first and foremost, smectites and the products of their modification, will be recognized as 21st century materials. Above all, this is due to the wide prospects for applications of nanosize composite materials — ceramics.

Following the strict definition of structure as a special network (framework) and structure formation as the formation and development of this spatial network (framework) it is logical to conclude that porosity is the main structural characteristic of building materials while the degree of development of the pore space is the primary kinetic characteristic of structure formation [1].

Most porous materials possess a complicated irregular stochastic structure. Individual pores, which together comprise the pore space, differ in shape, size, orientation and surface curvature [2].

The conventional method of pore formation in ceramic materials is to add consumable additives. The technological characteristics of building materials are changed by changing the number, types and size of consumable additives. A considerable number of works are devoted to this scientific direction. However, in our opinion, the effect of pores on the strength of materials has not been adequately studied.

Increasing the particle-size of the consumable additives and the sintering temperature of the samples decreases the pore size, which decreases the density and changes the strength characteristics. It has been determined that it is not so much the particle-size distribution of the consumable absorber that affects the strength characteristics as the ratio of the dispersity of the initial raw material and the dispersity of the additives.

The classical method of studying the pore space is mercury porometry. Analysis of the pore-size distribution in ceramic brick (Fig. 1) established that the average pore diameter is 2537 nm. Adding consumable absorbers into the mix results in a different pore-size distribution (Fig. 2), where the average pore size is now 3540 nm.

As the pore-size distribution curves show the overwhelming majority of the pores are smaller than 10 μm. Practice shows that the strength of materials is determined not by these pores but rather by the much more extended cracks, even though the contribution of these cracks to the pore space is small. At the Institute of Geology and Oil-Gas Technologies at the Kazan' Federal University x-ray computer tomography (XCT) was used to study such cracks.

We used XCT to study a sample of porous ceramic with density 0.48 g/cm^3 (Fig. 3).

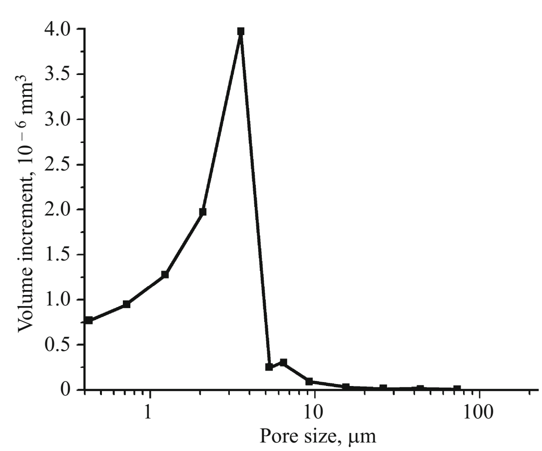

Fig. 1. Pore-size distribution in ceramic brick.

[1] P. P. Budnikov All-Russia Scientific-Research Institute of Building Materials and Structures, Kraskovo, Moscow Oblast', Russia.
[2] Scientific-Industrial Association Klinkernaya Keramika KFU, Kazan', Russia.
[3] Kazan' (Privolozh'e) Federal University (KFU), Kazan', Russia.
[4] Association of Manufacturers of Ceramic Wall Materials (Association APKSM), Moscow, Russia.
[5] E-mail: ashmarin@list.ru.

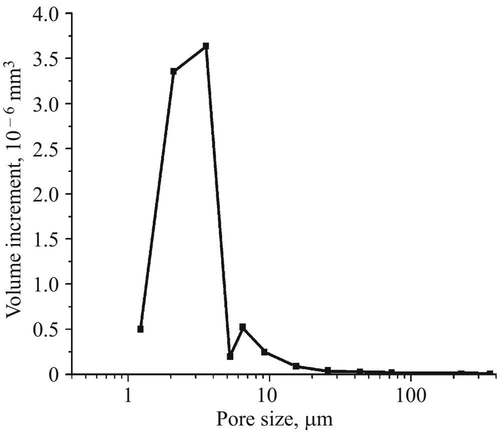

Fig. 2. Pore-size distribution in ceramic brick with consumable additives.

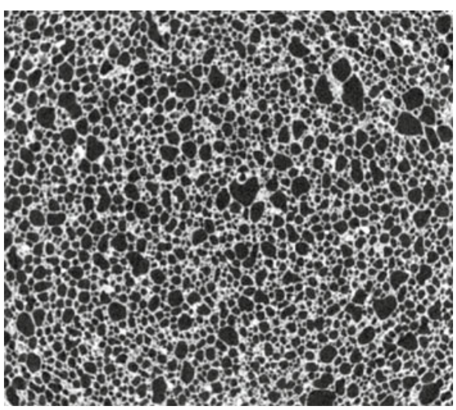

Fig. 3. XCT image of a porous ceramic with density 0.48 g/cm^3.

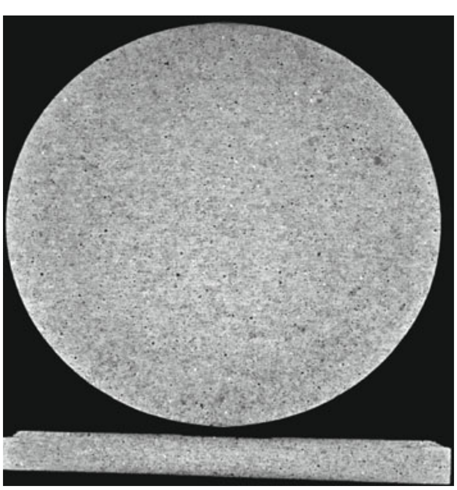

Fig. 4. XCT image of dense ceramic with density 1.88 g/cm^3 (sample diameter 45 mm, thickness 5 mm).

It is important that the tomograph perceives pores which communicate with one another as a single pore. The minimum size of pores visible by the XCT methods is 25 μm, and the average volume is 0.061 mm^3, which corresponds to linear size 400 μm. Therefore, it can be concluded that the overwhelming majority of the pores in the sample are closed. Indeed, even though the porosity is high, the sample's water absorption is only 5% and the compression strength is 8 MPa.

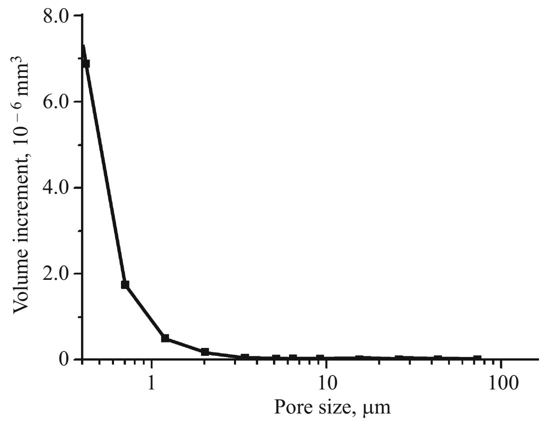

Fig. 5. Pore-size distribution in dense ceramic.

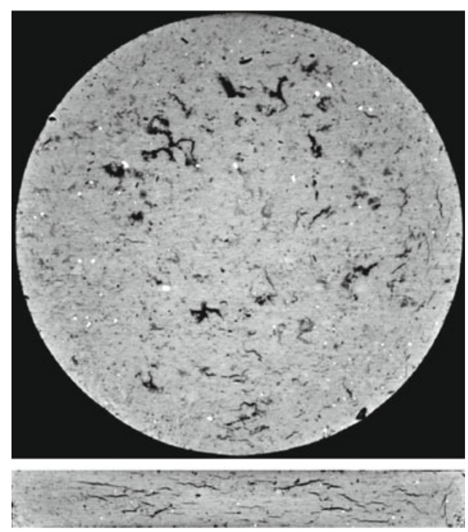

Fig. 6. XCT image of a ceramic with density 1.5 g/cm^3 (sample diameter 47 mm, thickness 5 mm).

Studies of ceramic material (Fig. 4) with density 1.88 g/cm^3 established that the pores are considerably smaller — their average diameter is 120 nm, while the average volume of the pores visible by the tomograph is 0.0036 mm^3, which corresponds to linear pore size 130 μm.

Pores of this size comprise a very small fraction in the pore-size distribution established by mercury porometry (Fig. 5).

The pores do not communicate with one another. As a result the sample's water absorption is low — <3%. The high strength (σ_c > 120 MPa) can be explained by the fact that cracks arising under load fade in fine pores.

A quite uniform structure and absence of visible defects are observed in both experimental samples.

At first glance the ceramic sample with density 1.5 g/cm^3 also appears to be distinguished by a uniform structure, but XCT reveals substantial defects (Fig. 6), specifically, cracks to 4 mm long, which predetermine its low strength characteristics. Under a load the cracks grow, causing the sample to fail.

In summary, XCT in combination with conventional methods of investigation makes it possible to determine the most dangerous defects in ceramic materials. Moreover, it is possible to determine why the defects form.

We believe that a structure in which the predominant pore sizes do not exceed 5 μm is very attractive for ceramic wall tiles. On the one hand such pores make it impossible for cracks to grow, while on the other hand their presence increases the heat-engineering properties of articles. Such articles are manufactured by, specifically, Alekseevskaya Keramika, JSC; they have proven themselves brilliantly in the construction of the objects at the Universiade [3].

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